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STANDARDIZED CATCH RATES IN BIOMASS FOR THE BLUE SHARK (*Prionace glauca*) CAUGHT BY THE SPANISH LONGLINE FLEET IN THE SOUTH ATLANTIC DURING THE PERIOD 1997-2013

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SUMMARY

Standardized catch rates per unit of effort (CPUE) were obtained for the stock of the South Atlantic blue shark (Prionace glauca) using General Lineal Models (GLM) for a total of 4027 trips of the Spanish surface longline fleet targeting swordfish, during the 1997-2013 period. The main factors considered were year, area, quarter, gear and ratio between swordfish and blue shark catches. The significant model explained the 87% of CPUE variability in blue shark. A major part of this variability was explained by the targeting criteria and the gear style. Other factors were also significant, but less important. The standardized CPUE obtained suggests a stable trend of the South Atlantic blue shark stock and differs substantially from the nominal CPUE trends observed during the period considered.

RESUMEN

Tasas estandarizadas de captura por unidad de esfuerzo (CPUE) fueron obtenidas para la tintorera (Prionace glauca) usando Modelos Lineales Generalizados (GLM) a partir de 4027 mareas realizadas durante el periodo 1997-2013 por la flota española de palangre de superficie que captura pez espada en el stock del Atlántico Sur. Los principales factores considerados en el modelo fueron año, área, trimestre, arte y el ratio entre la captura del pez espada y la tintorera. El modelo significativo explicó el 87% de la variabilidad de la CPUE. La mayor parte de la variabilidad de la CPUE fue explicada por el criterio de direccionamiento de los patrones de pesca y por el factor arte de pesca. Los otros factores considerados fueron menos importantes. La CPUE estandarizada obtenida sugiere una tendencia estable para este stock de tintorera del Atlántico Sur y difiere sustancialmente de la CPUE nominal observada durante el periodo considerado.

Key words: blue shark, sharks, CPUE, GLM, longline, Spanish fleet.

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Introduction

Generalized Linear Modeling techniques (GLM) (Robson 1966, Gavaris 1980, Kimura 1981) are regularly used to estimate standardized catch rates based on data from commercial fleets targeting swordfish with unbalanced spatial and temporal activity (i.e. Hoey *et al*. 1989, 1993; Anon. 1989, 1991; Nakano 1993, Mejuto 1993, 1994; Scott *et al*. 1993, Mejuto and De la Serna 1995, Mejuto *et al*. 1999, Ortiz *et al*. 2007). This type analysis is considered a basic routine task in the assessment of most large pelagic fish stocks in accordance with the scientific dynamics of the ICCAT and following the working plan recommended by the working groups of the respective species. This approach is also used to develop standardized catch rates (CPUE) of blue shark (*Prionace glauca)* and other large pelagic shark species such as shortfin mako and porbeagle. The standardized CPUE of blue shark caught by the Spanish longline fishery in the Atlantic Ocean was provided in a document previously submitted to ICCAT (Mejuto *et al.* 2009a). Scientific estimations of the total annual catches of these species-stocks are also regularly reported to ICCAT.

Catch rates are affected by stock abundance, but also by the fishing gear and the fishing strategy adopted by the fishermen, among other factors. In this case, the regular consistency in the fishing patterns of the Spanish fishery in the South Atlantic areas during the period analyzed, the information available on the gear used, fishing practices and other details, could facilitate the interpretation of these standardized CPUE indices as an abundance indicator of the blue shark stock.

Blue shark is a highly migratory oceanic-epipelagic and wide-ranging circumglobal species, distributed mostly, but not exclusively, between 50ºN-50ºS. This species is found in tropical, subtropical and temperate waters. Some specimens could also seasonally reach cold waters near the extreme latitudinal areas of their distribution and even coastal waters. The blue sharks have been fully retained onboard and landed by this fleet during the period under consideration, historically being the most prevalent bycatch species of this fishery (Mejuto *et al.* 2002, 2006, 2009b). Landings and catches are equivalent concepts in the Spanish longline fisheries for this species during the period analyzed.

This paper sets out to update the standardized CPUE series of the South Atlantic blue shark stock previously provided (Mejuto *et al.* 2009a) in preparation for further stock assessment and to examine the recent trends in relative abundance based on data obtained from this fleet.

Material and methods

The data used consisted of voluntary trip records obtained in a research covering the 1997-2013 period. Nominal effort was defined by thousands of hooks. The nominal trip catches of blue shark per unit of effort, assumed as the nominal CPUE of blue shark, were calculated as kilograms of gutted weight caught per thousand hooks.

The potential factors were tested to quantify the significance and relative importance of the main factors explaining the variance in catch rates. The factors used as explanatory variables were: year (17), quarter (4), area (5), gear (6), and ratio defined as the percentage of swordfish related to both the swordfish and blue shark caught (10 levels of 10% intervals), and the interaction quarter*area. The ratio factor makes it possible to categorize the types of trips, taking into account the progressive change in the fishing practices and the targeting criteria described for the Spanish longline fleet during the period considered, with implications in the preference of the skippers regarding swordfish and/or in favor of blue shark catches. The ratio factor might be a good proxy indicator of targeting intensity (Mejuto and De la Serna 2000, Anon. 2001).

The quarters and the spatial definitions used for GLM runs were the same as those used in previous analyses for the Atlantic blue shark (Mejuto *et al*. 2009a, García-Cortés *et al.* in press), assuming a hypothetical boundary line between North and South 'stocks' located at 5º N latitude.

The standardized log (CPUE) analyses were performed using the GLM procedure (*SAS 9.2*) based on previous research carried out on the Spanish longline fleet in the Atlantic and also used in the swordfish CPUE analysis of the Spanish as well as other Atlantic longline fleets (Mejuto and De la Serna 2000, Ortiz 2007, Ortiz *et al.* 2007, 2014;

Mejuto *et al*. 2009a, García-Cortés *et al.* in press). The final model defined includes 'year', 'quarter', 'area', 'ratio' and 'gear' as main factors, as well as the 'quarter*area' interaction: LOG (CPUE) = u + Y + Q + A + R + G + Q * A + e. Where, u= overall mean, Y= effect year, Q= effect quarter, A= effect area, R= effect ratio, G= effect gear, e= logarithm of the normally distributed error term.

Results and discussion

A total number of 4027 trip records were available during the periods 1997-2013 with an appropriate spatial-temporal coverage for the geographical distribution of the blue shark. The mean coverage of the observations accounts for 72% of the total blue shark catch-task I data. The trips were distributed over a wide range of fishing regions in the South Atlantic Ocean. Figure **1** shows the five areas considered for the GLM analysis.

Table **1** provides the ANOVA summary, including R-square, mean square error (root), F statistics and significance level as well as the Type III SS for each factor used. The significant model tested for the blue shark for the period 1997-2013 explained 87% of the CPUE variability for the South Atlantic blue shark stock.

The standard error, CV%, relative CPUE in biomass and upper and lower 95% confidence limits are shown (table **2)**. As in the case of previous swordfish analyses, the CPUE variability (Type III SS) in blue shark may be mainly attributed to the ratio and gear factors and, to a lesser extent, to other factors. The ratio factor takes into account the progressive change in the fishing practices and targeting criteria previously described for the Spanish longline fleet during the period under consideration, with implications in the preference of the skippers in favor of swordfish and/or the blue shark (Mejuto and De la Serna 2000). The inclusion of this factor in the models - or via a prior clustering classification of "similarities" among trips or sets based on the catch level by species composition - could have improved the interpretation of standardized CPUE as abundance indicators in the case of some fleets when qualitative changes in the fishing strategy - or other skipper's factors related to species preference - are detected or evidenced over time. In these cases, the option to handle these changes is to define a specific proxy well adapted to each case. Both species -swordfish and blue shark- frequently overlap in their areas of distribution, but their respective local abundance maximum regularly do not coincide. Low swordfish CPUE was regularly observed in this fleet in association with high catch rates of blue shark bycatch and *vice versa*. Similar approaches are frequently used for other Atlantic longline fleets when the criteria for target species are diffused or have changed over time (i.e., Anon. 2001, Chang *et al.* 2007, García-Cortés *et al* 2013, Hazin *et al.* 2007a,b; Mejuto and De la Serna 2000, Mourato *et al.* 2007, Ortiz 2007, 2010; Ortiz *et al.* 2007, 2010, 2014; Paul and Neilson 2007, Santos *et al.* 2014, Yokawa 2007) or in the case of fleets fishing in the Indian Ocean (i.e., Santos *et al.* 2012, 2013; Fernández-Costa *et al.* 2014).

Figures **2** and **3** show a normally standardized residual pattern, the normal probability *qq*-plot and the variability box-plot for standardized CPUE in biomass. The fitting of the model seems not to be biased and residuals are distributed normally.

Figure **4** shows the standardized CPUE in weight by year (with their respective 95% confidence intervals) and the scaled overall nominal catch rates versus scaled standardized CPUE of blue shark per year.

As already described in the case of the swordfish analyses, a significant increase in the nominal CPUE of blue shark was observed over 2000. During this period, most longline vessels introduced the monofilament "American" style and have progressively reduced the use of traditional-multifilament longline. So the nominal CPUE shows an unrealistic view of the abundance of the stock at that time since the observed increase had been caused by the change in the type of longlining. However, the standardized CPUE, in this case too, seems to represent well the effect caused by the change in type of gear and the new fishing strategy, showing a more realistic and stabilized standardized CPUE trend. The results obtained show a stable standardized CPUE trend over time for this stock during the period considered, in accordance with the most recent ICCAT assessment results.

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Table 1. Summary of ANOVA for CPUE analysis in biomass. GLM run: R square, mean square error (root) and F statistics. South Atl. Spain. LL BSH, CPUE in biomass**.** Dependent variable: log (CPUE) (gutted weight -GW-).

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	49	4647.59065	94.848789	563.45	<.0001
Error	3977	669.474626	0.168337		
Corrected Total	4026	6317.06528			

R-Square	Coeff Var	Root MSE	cpue1 Mean
0.874089	6.844018	0.410288	5.994847

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yr	16	20.295348	1.268459	7.54	<.0001
qtr	3	1.364993	0.454998	2.7	0.044
area	4	55.167343	13.791836	81.93	<.0001
gear	5	111.477974	22.295595	132.45	<.0001
ratio	9	2476.00231	275.111368	1634.29	<.0001
qtr*area	12	3.645976	0.303831	1.8	0.0419

Table 2. Estimated parameters: (lsmean), standard error (stderr), CV%, relative mean CPUE in biomass of blue shark (CPUE) (gutted weight –GW-) and upper and lower 95% confidence limits, for the Spanish longline fleet in the South Atlantic stock during the period analyzed 1997-2013.

Year	Lsmean	Stderr.	CV%	UCPUE	Mean CPUE	LCPUE
1997	5.80015	0.035447	0.611139367	354.340	330.557	308.371
1998	5.85546	0.038228	0.652860749	376.575	349.391	324.168
1999	5.86408	0.036008	0.614043465	378.156	352.387	328.374
2000	6.07486	0.035743	0.588375699	466.636	435.065	405.629
2001	5.96331	0.031479	0.527877974	413.852	389.089	365.808
2002	5.88976	0.032554	0.552722012	385.330	361.511	339.165
2003	5.78714	0.034995	0.604702841	349.444	326.279	304.650
2004	5.78408	0.037575	0.649627944	350.174	325.311	302.214
2005	5.91156	0.041702	0.705431392	401.084	369.605	340.596
2006	5.91047	0.038216	0.646581406	397.863	369.151	342.510
2007	5.93939	0.041330	0.695862706	412.092	380.026	350.455
2008	5.88346	0.038152	0.648461959	387.210	359.311	333.422
2009	5.97698	0.037725	0.631171595	424.806	394.529	366.410
2010	5.93734	0.039477	0.664893707	409.726	379.219	350.984
2011	5.95747	0.039178	0.657628154	417.808	386.926	358.327
2012	5.99295	0.041420	0.691145429	434.844	400.937	369.674
2013	6.03451	0.042548	0.705077960	454.325	417.974	384.531

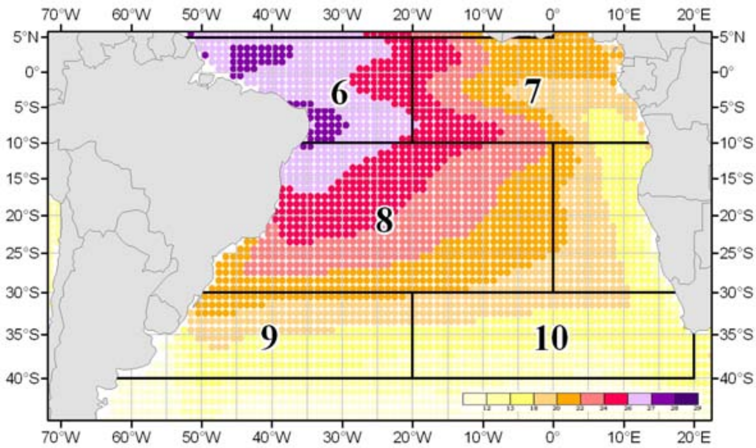

Figure 1. Geographical area stratification used for the GLM run of blue shark. The areas were kept as in previous GLM analyses. Areas are superimposed on average sea temperature (ºC) at 50m depth.

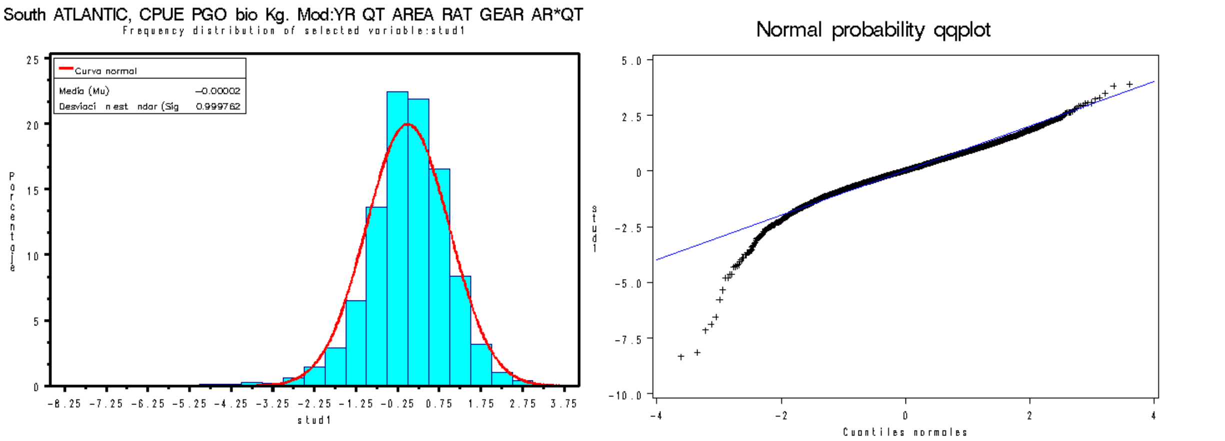

Figure 2. Distribution of the standardized residual of blue shark CPUE in weight (left) and normal probability *qq*-plots (right), in the South Atlantic for years 1997-2013 combined.

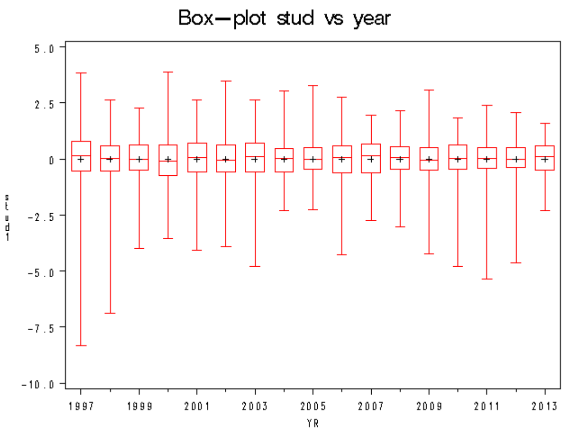

Figure 3. Box-plot of the standardized residuals versus year, for the South Atlantic blue shark during the 1997-2013 period.

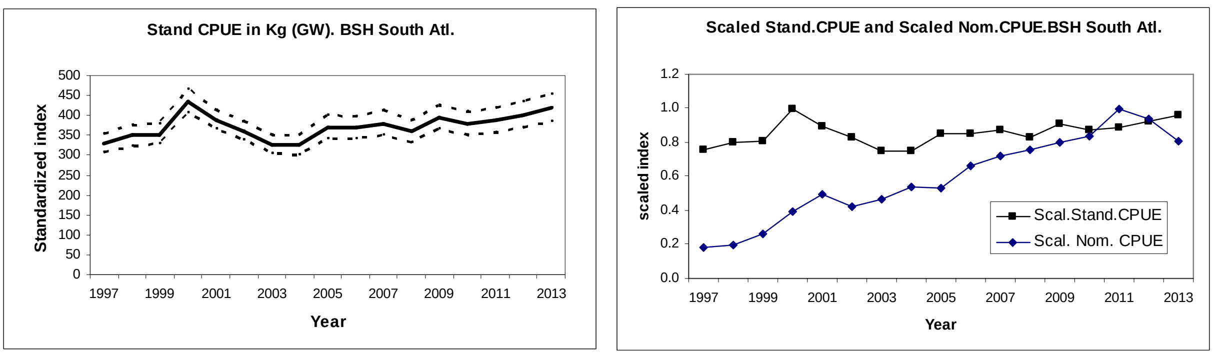

Figure 4. Standardized CPUE for the blue shark and 95% confidence intervals (left) and scaled standardized and nominal CPUE (right), for the South Atlantic blue shark stock, during the 1997-2013 period.